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Estimation of the Abundance
of Dall's Porpoise
(*Phocoenoides dalli*)
in the North Pacific Ocean
and Bering Sea

February 1981

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Estimation of the Abundance of
Dall's Porpoise (Phocoenoides dalli)
in the North Pacific Ocean and Bering Sea

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ABSTRACT

The Dall's porpoise task of the National Marine Mammal Laboratory conducted sighting surveys during 1978, 1979, and 1980 on board research vessels of the Government of Japan and vessels cooperating in the U.S. Platforms of Opportunity Program for the purpose of estimating the abundance of Dall's porpoise in the North Pacific and Bering Sea portions of its range. Analysis of the 1978 and 1979 surveys by strip and line transect methodologies led to estimates of abundance that ranged from 8.4×10^5 to 2.3×10^6 porpoise. The problems with these analyses include inaccurate angle and distance measurement and movement of the animals before being seen. These cause biases in the analyses, resulting in overestimates. When those biases are accounted for, a conservative estimate of Dall's porpoise abundance of 5.8×10^5 animals results.

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INTRODUCTION

There have been few reported studies on the abundance of Dall's porpoise (Phocoenoides dalli).

Hall (1979) conducted aerial and shipboard surveys in Prince William Sound and adjacent Gulf of Alaska waters. He estimated the population there to be 7,300 during the summer and 6,800 (in Prince William Sound alone) during the fall based on the aerial survey data. Since Hall did not present the results of his shipboard surveys or a very clear description of his analytical technique it is difficult to determine how accurate these estimates are. Green (1978) assumed the population in the eastern Pacific Ocean from the Oregon-California border southward to Cabo San Lucas, Baja California, and to 200 miles offshore, to be 250,000. This is only a crude approximation of the maximum population size based on several loose assumptions about the abundance of Dall's porpoise relative to common dolphins (Delphinus delphis) in the same area. No surveys were conducted.

Ohsumi and Takagi presented estimates of Dall's porpoise abundance, at the 1979 and 1980 meetings of the Scientific Subcommittee of the International North Pacific Fisheries Commission Ad Hoc Committee on Marine Mammals, that ranged from 5,000,000 to 10,000,000 porpoise for the entire range of the species. These estimates were based on a sighting model developed for large whales (Doi 1974) that is inappropriate for groups of animals and has several parameters in it that can result in overestimation of density and abundance when applied to porpoise schools. In this report the results of our analyses of the density and abundance of Dall's porpoise in the northern North Pacific Ocean and the Bering Sea, based on the data collected during 1978 and 1979, are presented.

DATA SOURCES AND ANALYTICAL METHODS

The population estimates presented here are based upon the sighting surveys conducted in 1978 and 1979 by U.S. biologists aboard Japanese salmon research vessels and U.S. Platforms of Opportunity Program (POP) vessels (Table 1). All of the data were extensively checked using the procedures developed for the POP program. This involves several levels of manual and computer checks which are detailed in Mercer et al. 1978. Numerical analysis was performed on the University of Washington CDC 6400 (NOS/BE operating system) using the programs listed in the Appendix. The strip transect model developed by Estes and Gilbert (1978) for analysis of aerial survey data for marine mammals was used for one set of estimates of population abundance, and a general line transect model (Burnham et al. 1980) was used for the comparative estimates. (For a brief general summary of transect survey methods see Eberhardt 1978).

TABLE 1.--Dall's porpoise (*Phocoenoides dalli*) sighting surveys conducted aboard U.S. Platforms of Opportunity Program and Japanese research vessels, 1978 and 1979.

Vessel	Observers	Cruise dates	Region surveyed
<u>1978</u>			
NOAA ship <u>Discoverer</u>	R. J. Beach T. W. Crawford	May 22 - June 12, 1978	Kodiak and the Alaska Peninsula
F/V <u>Sea Hawk</u>	T. W. Crawford	June 17 - Aug 15, 1978	Bristol Bay, Alaska Peninsula, Gulf of Alaska and the Inside Passage
M/V <u>Commander</u>	R. J. Beach	June 17, - Aug 30, 1978	Adak, Alaska, Gulf of Alaska, and the Inside Passage
NOAA ship <u>Surveyor</u>	D. Pippenger J. Babson	June 19 - July 10, 1978	Northern Gulf of Alaska
NOAA ship <u>David Starr Jordan</u>	J. Baumert C. Young	June 19 - Sept 3, 1978	California coast
NOAA ship <u>John N. Cobb</u>	C. Newby	June 19 - July 6, 1978	SE Alaska
NOAA ship <u>Discoverer</u>	D. Pippenger E. Bowlby	July 10 - Aug 17, 1978	Norton Sound, Bering Sea, Alaska Peninsula, and Pribilof Islands
NOAA ship <u>Surveyor</u>	A. Heindl J. Babson	Aug 7 - Aug 22, 1978 Aug 25 - Sept 16, 1978	Lower Cook Inlet, and the western Gulf of Alaska
NOAA ship <u>Discoverer</u>	C. Newby E. Hacker	Sept 10 - Oct 2, 1978	Norton Sound and the Pribilof Islands
U.S. Coast Guard Cutter <u>Rush</u>	G. Joyce	Oct 26 - Nov 28, 1978	Gulf of Alaska and the Bering Sea
<u>Oshoro Maru</u>	J. Peterson R. Read	June 5 - July 3, 1978 July 9 - Aug 4, 1978	S.E. Bering Sea Central North Pacific Ocean
<u>Hokuho Maru</u>	R. Rasmussen B. Long	July 6 - Aug 23, 1978	North Pacific and Bering Sea
<u>Hokusei Maru</u>	D. Ambrose T. Newby	July 16 - Aug 12, 1978	North Pacific (Emperor Sea mount)

TABLE 1.--Dall's porpoise (Phocoenoides dalli) sighting surveys conducted aboard U.S. Platforms of Opportunity Program and Japanese research vessels, 1978 and 1979 - continued.

Vessel	Observers	Cruise dates	Region surveyed
<u>1979</u>			
<u>Oshoro Maru</u>	L. Consiglieri	June 5 - July 3, 1979	Central North Pacific
<u>Oshoro Maru</u>	E. Hacker T. DeGange	July 7 - Aug 12, 1979	S.E. Bering Sea
<u>Hokusei Maru</u>	T. McIntyre L. Tsunoda	July 16 - Aug 6, 1979	North Pacific (Emperor Sea mount)
<u>Hoyo Maru 67</u>	C. Boucher, J. Coe, L. Jones, W. Walker	May 16 - June 23, 1979	N.W. North Pacific
<u>Hoyo Maru 67</u>	D. Ainley R. Beach	June 29 - Aug 10, 1979	Bering Sea

The following transformations of the data were made prior to calculation of the estimates.

1. The distance at which an animal was initially sighted and its direction (or angle) relative to the vessel were converted to a right angle distance from the cruise trackline. These right angle distances were used to determine whether a sighting occurred within the defined strip width. Observations of animals which were at distances greater than the strip width were not included in the analyses.
2. Beaufort state, visibility (in kilometers), and weather code data were combined and converted to the visibility codes used in the Platforms of Opportunity Program (Table 2). This was done so that data that were coded differently could be compared directly. Only sighting data collected during periods of adequate visibility (codes 1-4) were considered as acceptable for utilization in the abundance estimates. Sighting effort data collected in 1978 were biased because weather information was recorded only when an animal was sighted. In 1979 a new unit of sighting effort began with each change in weather. Since this was not done in 1978, some sighting effort data may have been collected during unacceptable weather conditions and included in the data used for the estimate. Examination of the field notes of the observers indicates that the magnitude of this source of bias is small.
3. Only sightings within the 180° arc in front of the vessel were used in the estimates.
4. Because there is little information available about the variation in the density of Dall's porpoise throughout its range, the surveyed portion of the range was divided into three regions and each region was analyzed separately. The areas are the Bering Sea, the Gulf of Alaska, and the west-central North Pacific (Figures 1, 2). The regions were arbitrarily defined so as to include all sightings of Dall's porpoise. Sighting effort data from areas in which no Dall's porpoise were observed during the study period were not included in the analysis since we defined surveyed areas where no porpoise had been sighted as outside the range of the species. (This resulted only in the exclusion of survey effort by the Oshoro Maru south of lat 40°N, during which only one sighting of Dall's porpoise was made.)

A large portion of the eastern North Pacific range of Dall's porpoise was not surveyed by U.S. observers during either 1978 or

TABLE 2.--Explanation of surface visibility codes used in the Platforms of Opportunity Program computer format and the conversion criterion for data weather information but no visibility codes.

Code	Explanation	Conversion criterion
1	<u>Excellent</u> - Surface of water calm, a high overcast solid enough to prevent sun glare. Marine mammals will appear black against a uniform gray background.	Beaufort = 0, visibility > 5 km, no glare
2	<u>Very Good</u> - May be a light ripple on the surface or slightly uneven lighting but still relatively easy to distinguish animals at a distance.	Beaufort = 1 or 2, visibility > 5 km
3	<u>Good</u> - May be light chop, some sun glare or dark shadows in part of the survey track. Animals up close (300 meters or less) can still be detected and fairly readily identified.	Beaufort < 3, visibility <u>></u> 5 km
4	<u>Fair</u> - Choppy waves with some slight whitecapping, sun glare or dark shadows in 50% or less of the survey track. Animals much farther away than 300 meters are likely to be missed.	Beaufort = 4 or Beaufort < 4 and visibility <u><</u> 1 km
5	<u>Poor</u> - Wind in excess of 15 knots, waves over 2 feet with whitecaps, sun glare may occur in over 50% of the survey track. Animals may be missed unless within 100 meters of the survey trackline, identification difficult except for the larger species.	Beaufort = 5 or Beaufort < 5 and visibility <u><</u> 500 m
6	<u>Unacceptable</u> - Wind in excess of 25 knots; waves over 3 feet high with pronounced whitecapping. Sun glare may or may not be present. Detection of any marine mammal unlikely unless the observer is looking directly at the place where it surfaces. Identification very difficult due to improbability of seeing animal more than once.	Beaufort <u>></u> 6 or Beaufort < 6 and visibility <u><</u> 300 m

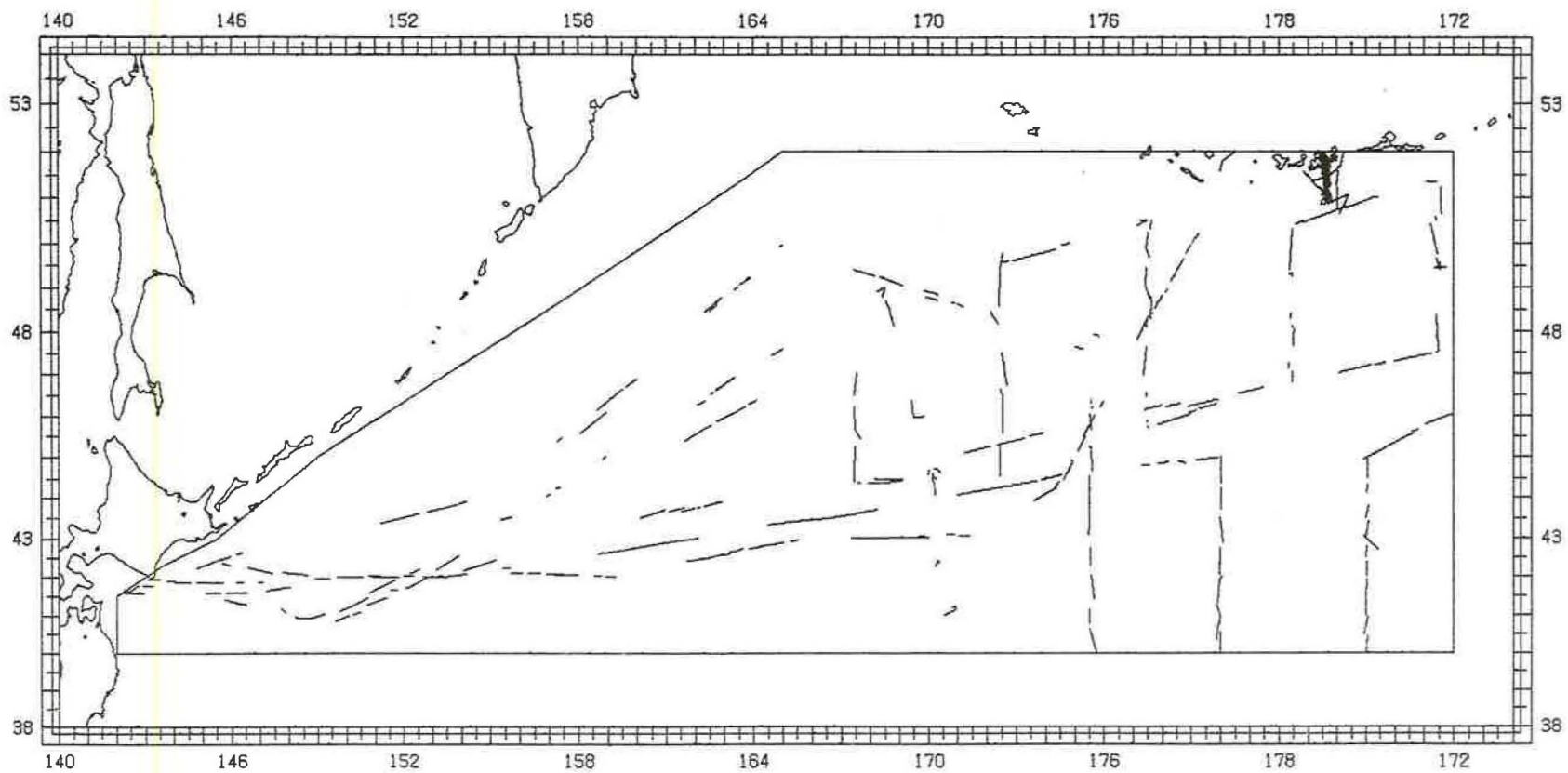


Figure 1A. Areas used for estimates of abundance of Dall's porpoise, 1978. Western-Central North Pacific.
(Lines inside area are the survey track lines.)

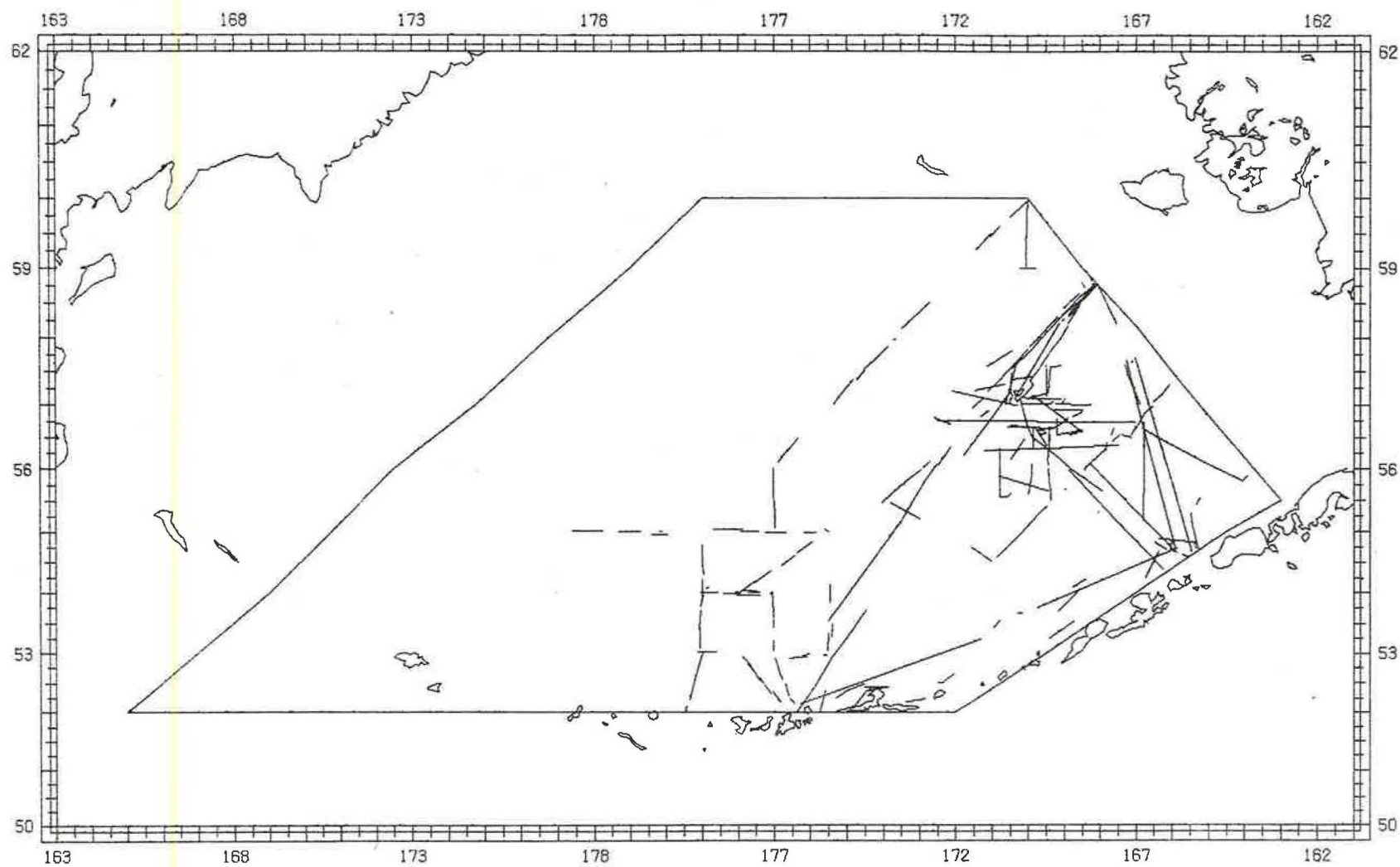


Figure 1B. Areas used for estimates of abundance of Dall's porpoise, 1978. Bering Sea.
(Lines inside area are the survey track lines.)

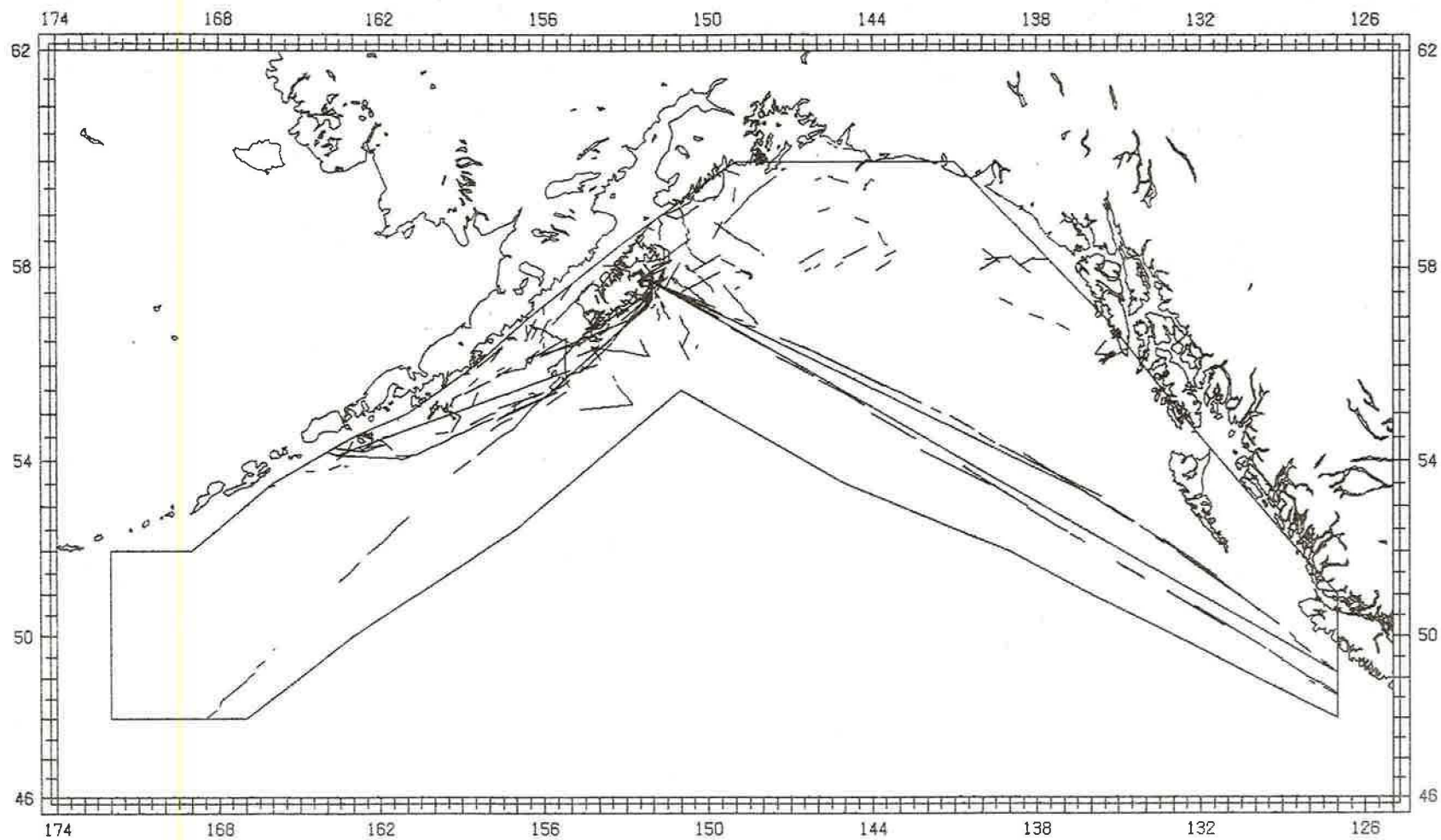


Figure 1C. Areas used for estimates of abundance of Dall's porpoise, 1978. Gulf of Alaska.
(Lines inside area are the survey track lines.)

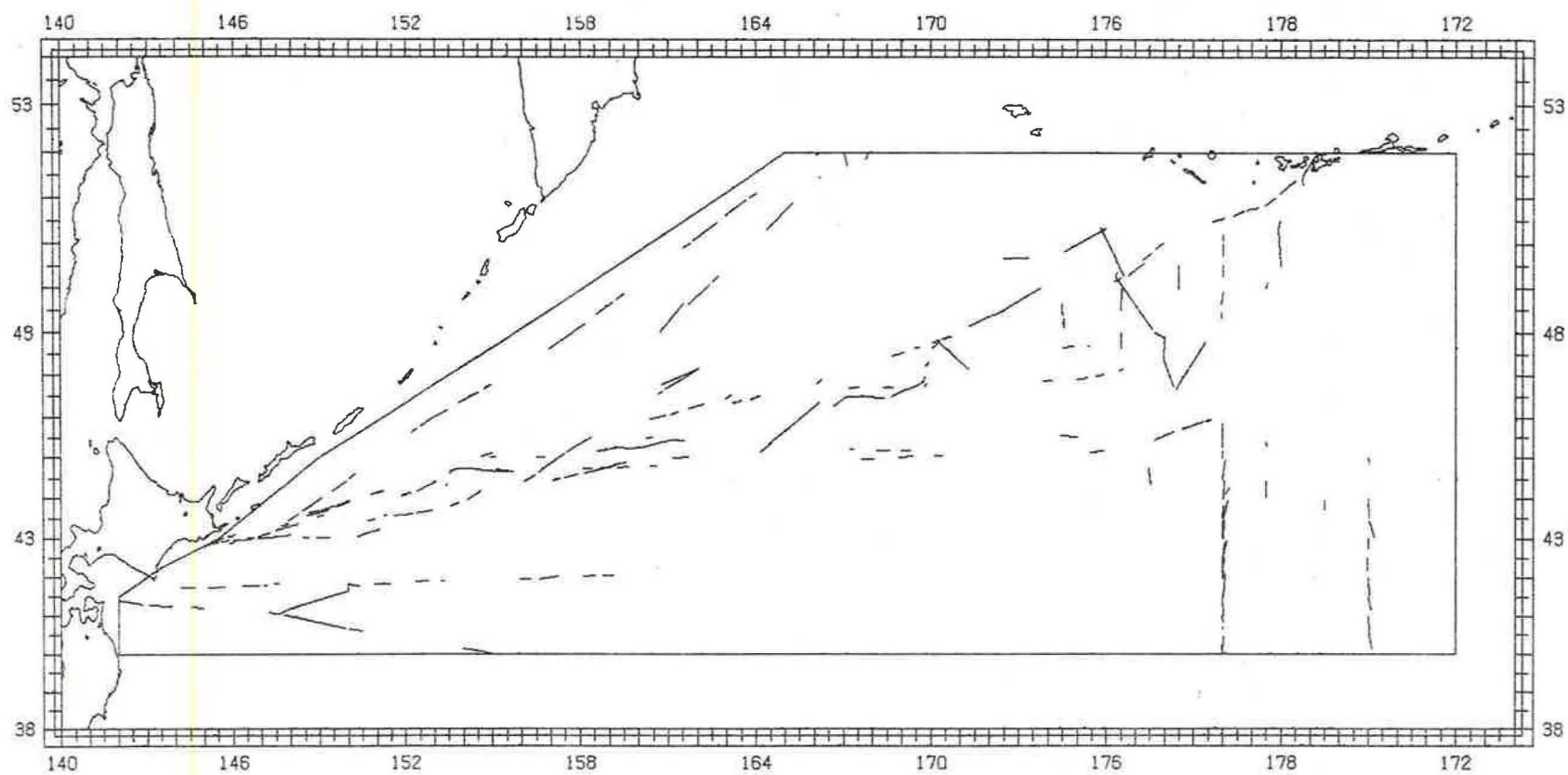


Figure 2A. Areas used for estimates of abundance of Dall's porpoise, 1979. Western-Central North Pacific. (Lines inside area are the survey track lines.)

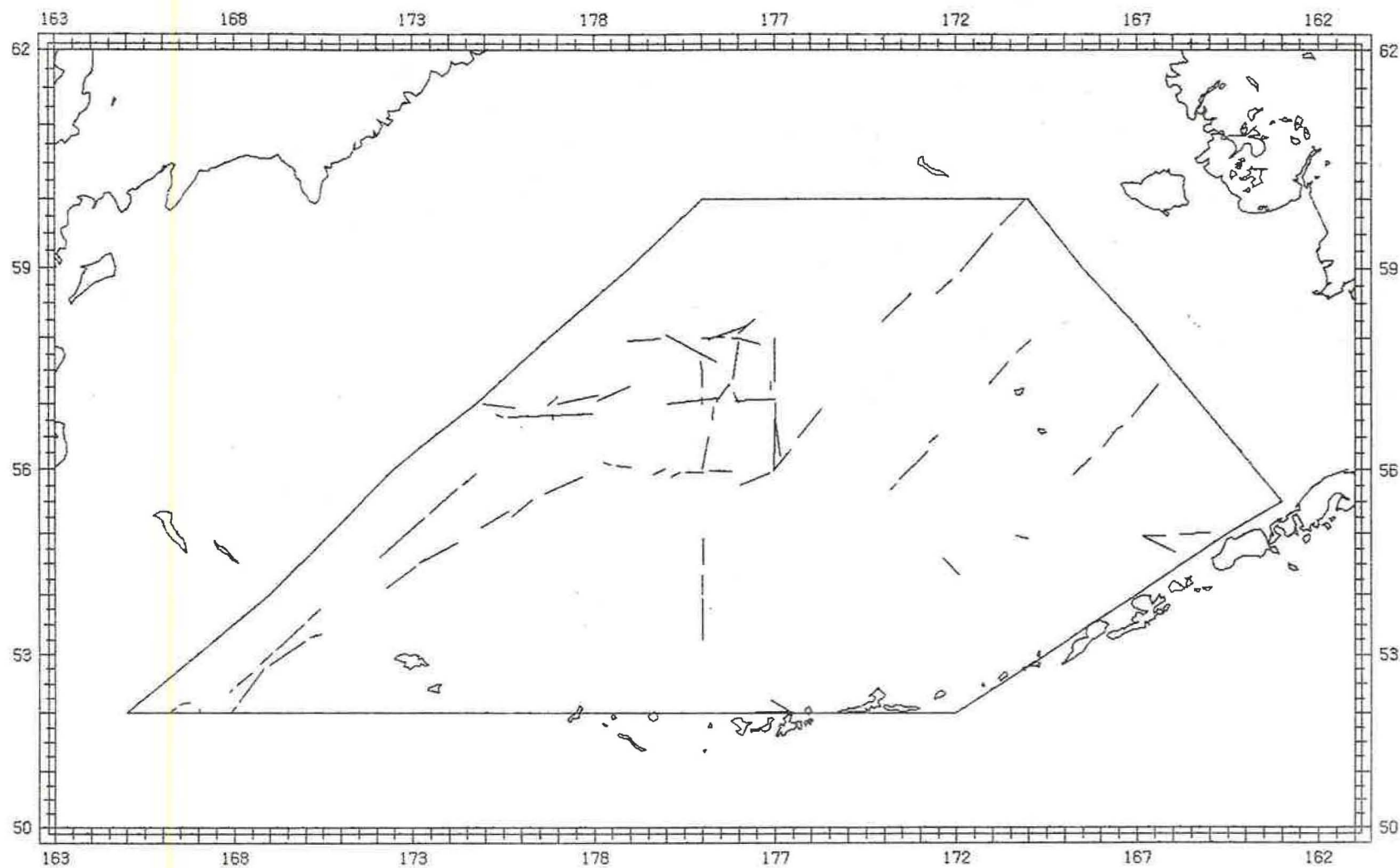


Figure 2B. Areas used for estimates of abundance of Dall's porpoise, 1979. Bering Sea.
(Lines inside area are the survey track lines.)

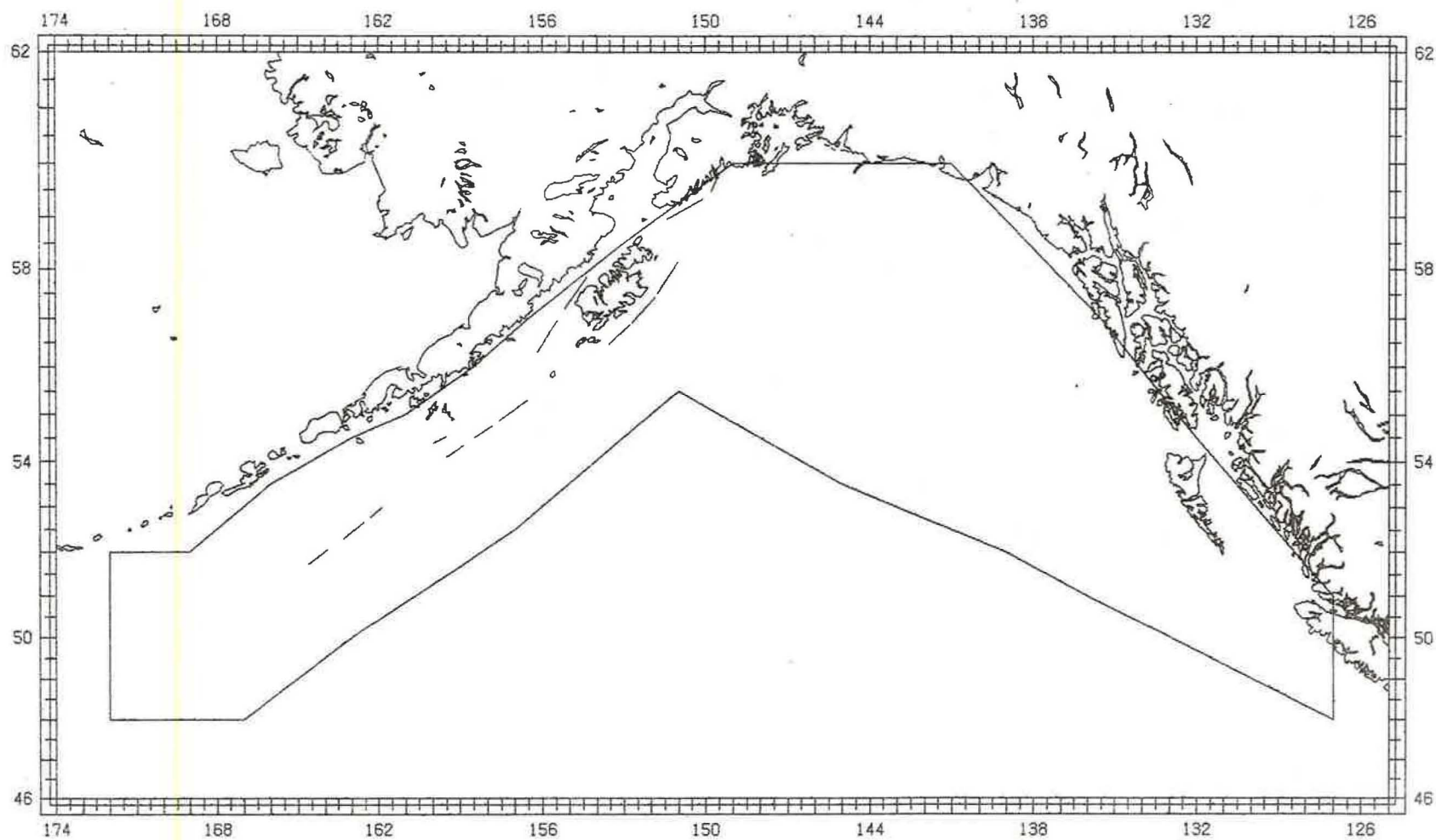


Figure 2C. Areas used for estimates of abundance of Dall's porpoise, 1979. Gulf of Alaska.
(Lines inside area are the survey track lines.)

1979. (Figure 3). An estimate of the abundance in this unsurveyed area south of the Gulf of Alaska was obtained by utilizing the weighted mean of the estimates for the adjacent areas of the west-central North Pacific and the Gulf of Alaska. The estimate is included because observations of Dall's porpoise have been recorded in the region from POP vessels during previous years.

5. Data from each of the 2 years were analyzed separately. The same three areas were used for analysis of 1978 and 1979 data.
6. Sightings of all Phocoenoides color morphs, including Dall's, True's, and unidentified Phocoenoides, were used for the estimation of Dall's porpoise density and abundance. (96% of all sightings were dalli type.)

STRIP TRANSECT ANALYSIS

Description of model

Estimates of the density and abundance of Dall's porpoise were calculated using "Method I" of Estes and Gilbert (1978) for strip transect analyses. In the strip transect model, a strip of uniform width is defined and only sightings that fall within that strip are used in the estimation.

The estimator has the following form:

For the estimated density:

$$\hat{R} = \sum y_i / \sum x_i \quad (1)$$

where R = the density of Dall's porpoise per square nautical mile,

y_i = the number of porpoise in the i^{th} transect strip,

and x_i = the area of the i^{th} strip.

An estimate of the variance of \hat{R} is

$$\hat{S}_{\hat{R}}^2 = \{ \sum (y_i^2 / x_i) - \hat{R} \sum y_i \} / (n-1) (\sum x_i) \quad (2)$$

where n = the number of strips.

For the estimate of abundance:

$$\hat{T} = \hat{R} A \quad (3)$$

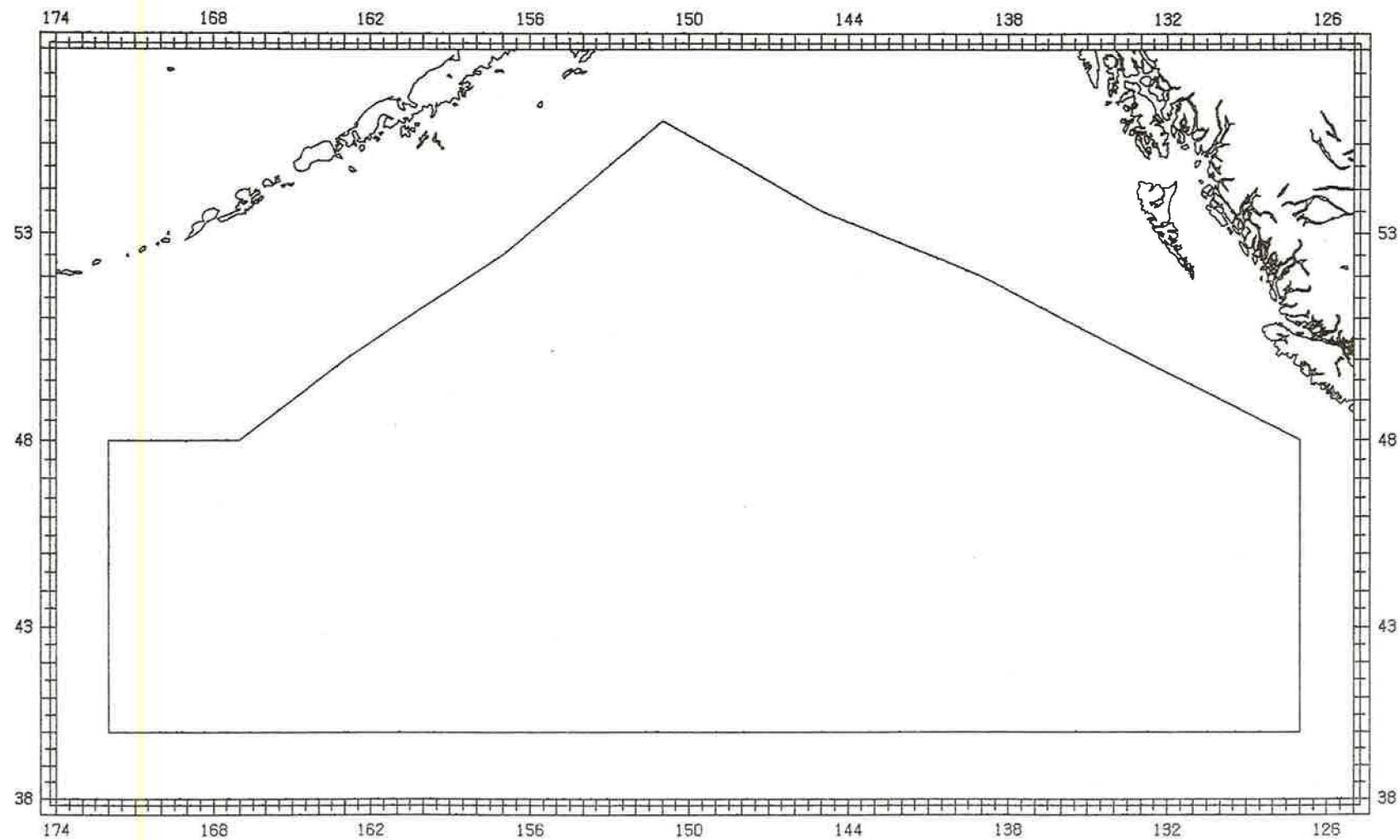


Figure 3. Unserved area of the Eastern North Pacific included in the abundance estimates.

where \hat{T} = the abundance of Dall's porpoise in a particular region,

and A = the total area of the region.

An estimate of the variance of T is

$$\hat{V}(\hat{T}) = A(A - \sum x_i) S_R^2 \quad (4)$$

where $\hat{V}(\hat{T})$ = the estimate of the variance of \hat{T} , and the other symbols are as previously defined. The 95% confidence interval for T is:

$$\hat{T} \pm t_{.05(2)(n-1)} \sqrt{\hat{V}(\hat{T})} \quad (5)$$

where $t_{.05(2)(n-1)}$ is the critical value at $\alpha = .05$ of the "t" statistic for a two-tailed test with $(n-1)$ degrees of freedom.

Choice of strip width

We tested the effect of strip width on abundance estimates, using 100, 200, 400, and 800 m widths. The 200 m strip width was chosen since it was the point at which the density estimates stabilized (i.e., as the strip was narrowed, density increased until the 200 m truncation point; there was no statistical difference between density estimates based on 100 and 200 m strips). This makes the 200 m strip-width the empirical choice. However, as explained below, for comparative purposes, abundance estimates were also calculated using a 400 m strip-width.

Preliminary analysis of the frequency of sightings versus the right angle distance (calculated from the initial sighting distance and the direction relative to the vessel) indicated a rapid decline in the frequency beyond 200 m (70% of the porpoises were sighted within 200 m of the vessel (Figure 4A). The highest frequency of sightings was at distances of less than 20 m (Figure 4B).

The distribution of sighting frequency could be related to two factors--a decline in the sighting rates with distance and the tendency for Dall's porpoise to be attracted to vessels. The effects of these factors on the strip transect estimates are quite different, as explained below.

If the probability of sighting animals decreases with distance within the strip, the assumption of the strip transect model that all animals within the defined strip-width are sighted is violated. As a result, using a strip width greater than 200 m results in a density estimate which is biased downwards, and therefore a lower estimate of abundance is obtained. Following this line of reasoning a strip-width of 200 m would yield a less biased estimate of abundance.

If the falloff of sightings beyond 200 m is a result of the tendency of Dall's porpoise to approach the vessel, then the assumption

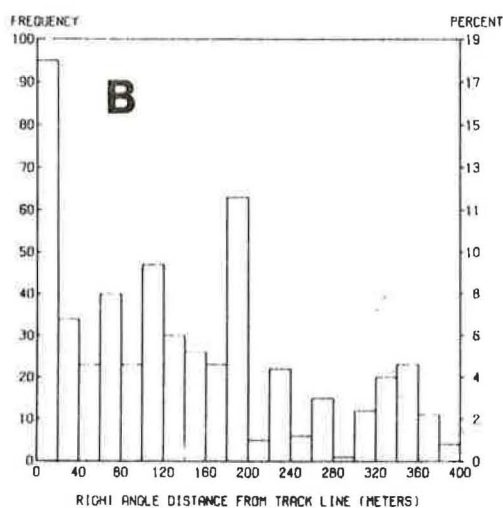
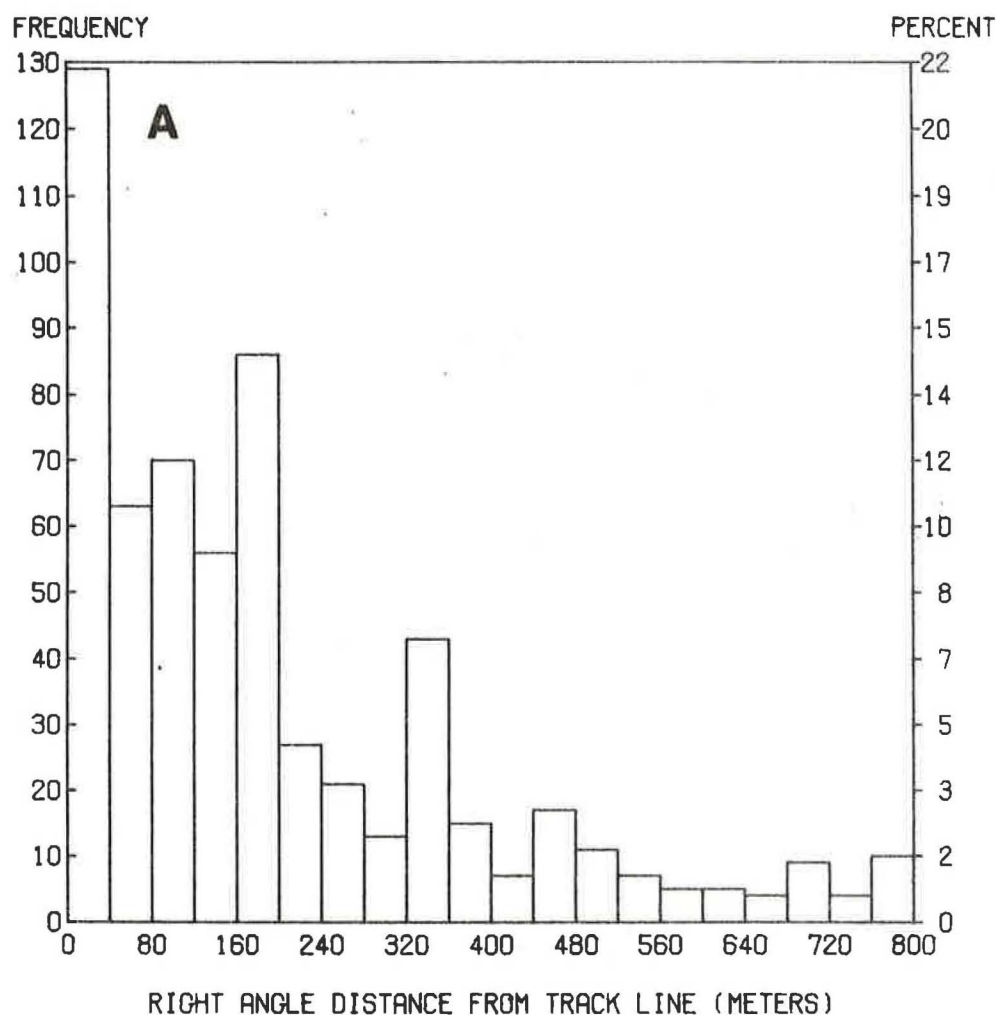


Figure 4. Frequency distribution of the calculated right angle distances of Dall's porpoise sightings from vessel tracklines, 1978 and 1979. Visibility codes 1-4.
 A) Distances of 0-800 m. B) Distances of 0-400 m.

that these animals do not move before being sighted is violated. If initial sighting distances were recorded from animals which had already approached the vessel when first seen by the observer, the density and abundance estimates based on a strip width of 200 m would be biased upwards. A wider strip could correct for this potential source of bias. Using a strip of too great a width could, however, result in violating the assumption that all animals within the strip are seen. Since it is clear from the data that the frequency of sightings beyond 400 m decreases rapidly this was chosen as the cutoff point. Estimates for both strip widths are therefore included for comparison.

Results

The estimates for the abundance and density of Dall's porpoise based on the strip censuses are presented in Tables 3 and 4. Mean group size was calculated for each area for the 400 m strip and is presented in Table 4. The abundance estimates range from a low of 837,000 to a high of 1,821,000 for the northern North Pacific and Bering Sea portions of the range of the species (3.3 million nmi²). In general, the densities and abundance based on the 200 m strip width data were larger by approximately 50% than the estimates based on the 400 m strip width.

LINE TRANSECT ANALYSIS

Description of Model

For the the line transect model, the data were stratified by area and weather condition as they were for the strip transect. The major difference between line and strip transect analyses is that rather than truncate the data as is done when doing a strip transect (i.e., excluding sightings outside the strip), in line transect analysis a correction is made for the probability of missing some sightings away from the track line. (For more details, see Burnham et al. 1980.)

The exponential polynomial estimator of the probability density function was chosen to minimize the bias caused by animal movement as discussed in the previous section. Burnham et al., (1980) showed that the exponential polynomial estimator was more robust to movement (i.e., was less biased) than the other estimators tested.

This estimator has the following form (Burnham et al 1980):

$$f(x) = \frac{1}{\mu} e^{-(ax+bx^2)} \quad (6)$$

where $f(x)$ = Probability density function = detection function,

$$\mu = \text{normalizing constant} = \int_0^{\infty} e^{-(ax+bx^2)} dx, \quad (7)$$

and x = right angle distance from the trackline.

TABLE 3.--Abundance and density estimates for Dall's porpoise based on data collected during shipboard sighting surveys. Estimates based on strip transect using 200 meter strip width.

Stratum	Stratum ₂ ^{1/} area (NMI ²)	Percent of area sampled	Transects in stratum =N	Dall's porpoise counted	Density (\hat{R}) individuals/ NMI ²	Variance $S^2_{\hat{R}}$	Abundance \hat{T}	Variance Var (\hat{T}) (millions)	95% confidence interval around \hat{T}
<u>1978</u>									
Western-central North Pacific	1,029,633	.151	526	583	.376	.00675	386,831	7,149.6	(220,723 - 552,940)
Bering Sea	309,874	.227	307	159	.226	.00326	70,108	312.2	(35,339 - 104,877)
Gulf of Alaska	<u>493,958</u>	.303	567	769	.514	.00811	<u>253,865</u>	1,973.9	(166,601 - 341,130)
Totals:									
Surveyed area	1,833,465						710,804		
Eastern North Pacific (unsurveyed)	<u>1,429,218</u>				.442 ^{2/}		<u>(631,714)</u>		
Total surveyed and unsurveyed	3,262,683						1,342,518		
<u>1979</u>									
Western-central North Pacific	1,029,633	.081	207	362	.432	.00754	445,230	7,982.7	(269,080 - 621,380)
Bering Sea	309,874	.123	73	214	.562	.01116	173,995	1,070.4	(108,775 - 239,215)
Gulf of Alaska	<u>493,958</u>	.020	16	101	1.007	.12474	<u>497,451</u>	30,429.6	(125,639 - 869,263)
Totals:									
Surveyed area	1,833,465						1,116,676		
Eastern North Pacific (unsurveyed)	<u>1,429,218</u>				.493 ^{2/}		<u>(704,604)</u>		
Total surveyed and unsurveyed	3,262,683						1,821,280		

^{1/} Stratum areas are approximated by straight line integration.

^{2/} Density was obtained from weighted mean of western-central North Pacific and Gulf of Alaska.

TABLE 4.--Abundance and density estimates for Dall's porpoise based on data collected during shipboard sighting surveys. Estimates based on strip transect using 400 meter strip width.

Stratum	Stratum area (NMI ²) ^{1/}	Percent of area sampled	Transects in stratum =N	Dall's porpoise counted	Density (\hat{R}) individuals/NMI ²	Variance S^2_R	Abundance \hat{T}	Variance Var (\hat{T}) (millions)	95% confidence interval around T	Mean group size
1978										
Western-central North Pacific	1,029,633	.301	526	777	.250	.00191	257,777	2021.5	(169,452 - 346,102)	4.466
Bering Sea	309,874	.454	307	298	.212	.00191	65,699	182.9	(39,084 - 92,314)	4.448
Gulf of Alaska	<u>493,958</u>	.606	567	828	.277	.00204	<u>136,671</u>	495.8	(92,935 - 180,407)	6.900
Totals:										
Surveyed area	1,833,465						460,147			
Eastern North Pacific (unsurveyed)	<u>1,429,218</u>				.264 ^{2/}		<u>(373,313)</u>			5.476
Total surveyed and unsurveyed	3,262,683						837,460			
1979										
Western-central North Pacific	1,029,633	.163	207	433	.259	.00237	266,277	2510.0	(167,502 - 365,052)	4.047
Bering Sea	309,874	.246	73	303	.398	.00572	123,179	548.3	(76,499 - 169,858)	3.523
Gulf of Alaska	<u>493,958</u>	.041	16	151	.753	.09266	<u>371,857</u>	22,598.5	(51,440 - 692,274)	5.808
Totals:										
Surveyed area	1,833,465						761,313			
Eastern North Pacific (unsurveyed)	<u>1,429,218</u>				.312 ^{2/}		<u>(445,916)</u>			4.402
Total surveyed and unsurveyed	3,262,683						1,207,229			

^{1/} Stratum areas are approximated by straight line integration.

^{2/} Density was obtained from weighted mean of western-central North Pacific and Gulf of Alaska.

The density of groups is calculated from:

$$\hat{D}_g = \frac{n \hat{f}(0)}{2 L} \quad (8)$$

where \hat{D}_g = density of groups,

n = number of groups sighted,

$\hat{f}(0) = f(x)$ at $x=0$,

and L = line length.

This has an estimated variance of:

$$\hat{\text{Var}} (\hat{D}_g) = (\hat{D}_g)^2 [(\hat{\text{CV}} (n))^2 + (\hat{\text{CV}} f(0))^2] \quad (9)$$

where $\text{CV}(\cdot)$ = coefficient of variation.

The density of individuals is simply:

$$\hat{D}_i = \bar{G} \hat{D}_g \quad (10)$$

where \hat{D}_i = density of individuals

and \bar{G} = mean group size = $\frac{\text{total number of animals}}{\text{total number of groups}}$

This has an estimated variance of:

$$\hat{\text{Var}} (\hat{D}_i) = (\hat{D}_i)^2 [(\hat{\text{CV}} (\bar{G}))^2 + (\hat{\text{CV}} (\hat{D}_g))^2] \quad (11)$$

From this it follows that the abundance is:

$$\hat{T} = A \hat{D}_i \quad (12)$$

where \hat{T} = Total abundance,

and A = Total area surveyed.

This has an estimated variance

$$\hat{\text{Var}} (\hat{T}) = A^2 \hat{\text{Var}} (\hat{D}_i) \quad (13)$$

Where $\hat{\text{Var}} (\hat{T})$ = the estimate of the variance of \hat{T}

The approximate 95% confidence interval around T was constructed assuming an approximation of a normal sampling distribution for D_i .

$$\hat{T} \pm 1.96 \sqrt{\hat{\text{Var}} (\hat{T})} \quad (14)$$

Results

The estimates for density and abundance based on the line transect analysis are summarized in Table 5. The abundance estimates based on the 1978 and 1979 data were 920,000 and 2,327,000 animals respectively.

DISCUSSION

Three different analyses based on two different years' sighting effort has resulted in six estimates of Dall's porpoise abundance ranging from 840,000 to 2.3 million. The problems associated with the use of strip transect analysis have been briefly discussed in the section on choice of strip width; they reduce to the choice of a strip width sufficiently narrow so that no animals are missed within the chosen strip area and so that no animals move into the strip before being seen.

The problems of applying line transect methodology to shipboard sighting surveys of Dall's porpoise involve violations of some of the basic assumptions of the line transect theory. The following are the four basic assumptions (Burnham et al. 1980; order of importance from most to least critical) and a discussion of how these assumptions are or are not violated by our data.

1) Points (= animals) on the line will never be missed (i.e., they are seen with a probability of 1). In general, this assumption is met since poor weather conditions are excluded from the analysis and Dall's porpoise have short dive intervals.

2) Points are fixed at the initial sighting position, a) they do not move before being detected, and b) none are counted twice. This assumption is the one least likely to be met in our surveys for the following reasons:

a. Dall's porpoise are capable of continuously swimming at speeds of 10-15 knots (5-7.5 m/sec) and in bursts can achieve speeds in excess of 20 knots (10m/sec, Norris and Prescott, 1961). If an observer of a group of Dall's porpoise (swimming at 5 m/sec) takes 10 to 20 sec to obtain positive identification and estimation of distance, the animal would have moved as much as 100 m. Depending on the direction of travel (toward or away from the vessel), the estimate of distance will be biased high or low with an inverse effect on the estimate of density.

The problem of animal movement away from the transect line is discussed extensively in Burnham et al. (1980). They present simulation studies showing that for this type of movement, the exponential polynomial estimator is substantially more robust (i.e., shows lower percent relative bias) than the Fourier series estimator which otherwise would be the estimator of choice. However, when movement is extreme, bias can still be as high as -50% to -70%. In the case of Dall's porpoise, our observations support the hypothesis that more are attracted to the vessels than repelled by them. The behavior of the estimators

TABLE 5.--Abundance and density estimates for Dall's porpoise based on data collected during shipboard sighting surveys. Estimates based on line transect using exponential polynomial fall off curve.

Stratum	Stratum ² area (NMI ²) ^{1/}	Transect Length NMI	Dall's porpoise groups counted	Density (\hat{D}_g) Groups/NMI ²	Coefficient of variation CV (\hat{D}_g)	Mean Group Size (\bar{G})	Coefficient of variation CV (\bar{G})	Density (\hat{D}_i) Individuals/NMI ²	Variance Var \hat{D}_i	Abundance \hat{T}	Variance Var (\hat{T}) (millions)	95% confidence interval around \hat{T}
1978												
West-central North Pacific	1,029,633	7046	243	.0796	.064	4.0247	.001313	.3205	.0004208	329,942	446.1	288,546-371,339
Bering Sea	309,874	4590	83	.0365	.243	4.0723	.02328	.1485	.001314	46,021	126.2	24,002-68,040
Gulf of Alaska	<u>493,958</u>	9396	121	.0405	.092	7.0413	.0004011	.2855	.0006897	<u>141,002</u>	168.3	115,577-166,428
Totals:												
Surveyed area	1,833,465									516,965		
Eastern North Pacific (unsurveyed)	<u>1,429,218</u>			.0561 ^{2/}		5.0275 ^{2/}		.2818 ^{2/}		<u>(402,741)</u>		
Total surveyed and unsurveyed	3,262,683									919,706		
1979												
West-central North Pacific	1,029,633	3732	115	.1465	.093	4.0696	.003195	.5962	.003078	613,863	3,263.0	501,902-725,824
Bering Sea	309,874	1623	112	.1532	.095	3.4911	.004433	.5348	.002587	165,732	248.4	134,839-196,625
Gulf of Alaska	<u>493,958</u>	432	19	.2263	.320	5.4211	.009420	1.2268	.1542	<u>605,985</u>	37,635.7	225,746-986,223
Totals:												
Surveyed area	1,833,465									1,385,579		
Eastern North Pacific (unsurveyed)	<u>1,429,218</u>			.1546 ^{2/}		4.2612 ^{2/}		.6588 ^{2/}		<u>(941,542)</u>		
Total surveyed and unsurveyed	3,262,683									2,327,121		

^{1/} Stratum areas are approximated by straight line integration.

^{2/} Density and mean group size obtained as the weighted mean of western-central North Pacific and Gulf of Alaska.

under this situation has not been tested, but it is obvious that the bias caused by movement toward the vessel will be positive. Thus the exponential polynomial estimator was chosen for this analysis since: 1) it was assumed that this estimator might be as robust for movement toward the line as for movement away and 2) there were serious problems with getting the Fourier series estimator to fit the data (i.e., the sensitivity of the Fourier series estimator resulted in pronounced oscillations in the estimated probability density function). If it can be further assumed that the percent relative bias caused by animals moving toward the line would be of the same magnitude as that caused by animals moving away from the line then the density and abundance estimates can be biased by as much as +60%.

b. Dall's porpoise can easily overtake and pass a vessel steaming at 10 knots, the mean cruising speed of vessels used in these surveys. The probability of repeat sightings of individuals as a consequence of this behavior is not quantified at this time but could be high. This will also give a positive bias to the estimate of density.

3) Distances and angles are measured exactly; thus neither measurement errors nor rounding errors occur.

The measurement of distance at sea is extremely difficult. Attempts have been made to use rangefinders for distance measurements. The speed with which these animals move and the lack of resolution of rangefinders at distances in excess of a few hundred meters has necessitated use of observer estimated distances in the analysis. In 1978 most distances were recorded to an accuracy of 0.1 nm (185 m). An attempt to get greater accuracy was begun during 1978, by recording all distances to 10's of meters. While this permitted greatly improved distance recording at short distances, longer distances tended to be grouped at 100 m intervals.

Angles tended also to be grouped. While they were recorded in ten's of degrees, clustering of angles was observed at 40° and 90°. This is most likely a result of the difficulty in accurately taking a bearing on a group of animals when the vessel is yawing, compounded by animal movement.

Both of these measurement problems will tend to increase the variance of the estimate without necessarily changing the magnitude. Grouping the data into intervals and analyzing the grouped data would quantify this increased variance, but at present there is no method for analyzing grouped sighting distances and grouped angles by line transect methodology. (The strip transect may minimize some of these problems since the exact location of an animal (or group) is not important if you can determine whether or not it is within the chosen strip.)

4) Sightings are independent events. Sightings of porpoise schools appear to be independent events (i.e., the sighting of one school does not increase the probability of sighting another; therefore this assumption is not violated.

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The range of estimates of the abundance of Dall's porpoise in the North Pacific Ocean and Bering Sea presented in Tables 1-3 is 840,000 to 2,300,000 animals. We are left with the problem of choosing the best estimate. The strip transect analysis may effectively deal with the problems of estimation of distances and angles. However since the determination of effective strip-width still has some problems due to the movement of the animals and this method is quite sensitive to the choice of strip width, these results can only be considered as within the range of possible estimates.

The line transect analysis does not have this problem, but the estimates from the two different years are quite different. Since there was much less survey effort in 1979 (approximately 25% of 1978) the estimate based on that data is much less reliable (i.e., the variance is much greater). Thus it is our belief that the estimate of the abundance of Dall's porpoise throughout the range of 920,000 animals obtained from the line transect analysis of the 1978 data, is our best estimate. Recall however from the discussion of animal movement that this could be biased by as much as +60%. If the bias is of that magnitude, the actual abundance would be 575,000 animals.

It should be noted that this estimate of abundance throughout the entire North Pacific range of Dall's porpoise is based on an assumption of uniform density within each of the described areas. As more sampling is carried out it may be possible to further stratify the areas into smaller regions of like density. This could improve the estimates if there were regions of very high or low density within the surveyed areas and if survey effort could be allocated to each stratum. Since at present most of our survey work is performed on vessels conducting other research, this is not possible.

It is obvious from the previous discussion that there are serious problems with the estimation of Dall's porpoise density and abundance from shipboard surveys. The problem of inaccuracies in recording sighting distances and angles has been minimized in 1980 by the use of only highly skilled observers with extensive field experience. (Some of the observers sent out in 1978 had less training and experience than we would have liked.)

There is still a need for a method of analyzing grouped sighting distances and angles, since even the best observers cannot be as accurate at sea as current line transect methodology requires. This problem was discussed at the recent International Whaling Commission Committee meeting on the Design of Sighting Surveys (Seattle, September 1980), and the development of a solution is being considered by some of the participants.

The problem of attraction to/avoidance of the vessel by Dall's porpoise is a difficult one to cope with. During June and July 1980 we attempted an experiment using a helicopter off the NOAA research vessel Surveyor, running radial transects out from the ship. The objectives were two-fold: first, to obtain an independent density estimate from an aerial survey of the same region that the vessel was surveying and second to observe the

direction of movement (relative to the ship) of any porpoise observed from the helicopter. Problems with the navigation system onboard the helicopter and poor weather forced the cancellation of this study before completion.

Aerial surveys of the fishing grounds would also be desirable, since an aircraft can survey a higher percentage of an area than a ship can in the same time. Logistical problems such as the availability of airfields and unstable weather conditions in the area may make aerial surveys impossible.

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APPENDIX

Computer programs used for data preparation and analysis, their authors and descriptions. Further information regarding any of these programs may be obtained by contacting the author of this report.

<u>Program</u>	<u>Author</u>	<u>Function</u>
QCPI	R. M. Sonntag	Comprehensive quality control program for POP format transect data (Mercer et al. 1978)
ABUN	B. D. Krogman	Calculates density, abundance and related sample statistics using the strip transect model of Estes and Gilbert (1978)
AMP	R. M. Sonntag	Comprehensive mapping program used to plot transects and sightings (Sonntag 1980)
POLYGON	R. G. Punsley, modified by R. M. Sonntag and G. C. Bouchet	Calculates intersections of transect lines with side of survey areas; inserts time and position of intersection into data base to preserve survey effort
PAREA	R. M. Sonntag	Approximates the area of a cartographically defined polygon by straight line integration
TRANSECT	J. L. Laake, K. P. Burnham, and D. R. Anderson	Calculates density and related sample statistics using various line transect models (Laake et al. 1979)
TRLEN	G. C. Bouchet	Takes output from polygon program, calculates transect lengths and excludes off effort, poor visibility, and non-Dall's porpoise sightings and prepares data for input to program TRANSECT.

